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Joint Resource Allocation Scheme for Device-To-Device Communication under a Cellular Network

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Abstract: *Device-To-Device* (*D2D*) *communication is a new technology that allows the mobile terminals to directly communicate with each other by sharing the resources of the cellular network under the control of a cellular system. D2D communication was introduced into the cellular network in order to improve the efficiency of resource utilization and increase the system throughput. However, there exist interferences between D2D links and cellular links due to the resource reuse. In order to efficiently limit the cases of interference, a joint resource allocation scheme for D2D communication under a cellular network is proposed. The scheme, based on the user's Quality of Service* (*QoS*)*, defines a new utility function to balance the increasing system throughput and the interference in the cellular users D2D communication. The optimal D2D transmitting power is obtained through optimizing the utility function by using the convex optimization theory. The simulation shows that the scheme can fulfill the user's QoS requirements efficiently, improve the system throughput and the reliability of the resources as well.*

Keywords: *D2D, cellular network, resource allocation, power control, convex optimization.*

1. Introduction

The wireless communication network has been developed for higher data rate, greater resource utilization and higher network capacity [1]. However, due to the limited spectrum resources available in the wireless network, the problem how to achieve this goal has become the focus of the research in industry. In order to make use of the bandwidth resource efficiently and improve the network throughput, more and more researchers pay attention to D2D communication technology. D2D communication can co-exist with the existing cellular wireless communication systems and few changes are needed in the system structure. D2D communication technology makes D2D users use the cellular resources under the control of the cellular network, which can enhance the spectrum efficiency of the cellular communication system, offload the data of the cellular network, increase the data rate and reduce the energy consumption of the mobile terminals.

There are two main types of resource allocations for D2D communication in the cellular network: orthogonal resource allocation and sharing resource allocation. The interference caused by the orthogonal resource allocation has lower resource utilization; on the contrary, the interference caused by the sharing resource allocation has higher resource utilization. Due to the shortage of the spectrum resource, the sharing resource allocation is currently dominating. D2D communication will cause the corresponding interference to the cellular users because of reusing the resources of the cellular system, therefore, the users of the cellular system and D2D need to coordinate with each other to reduce the interference and ensure normal communication through the system [2].

There are many studies about resource allocation and interference management. In [3] models of D2D resource allocation into an integer nonlinear optimization problem are presented, that optimize the whole throughput of the cellular network and D2D through an heuristic algorithm with the constraint of a minimum Signal to Interference and Noise Ratio (SINR) requirement. In [4] the authors propose an interference-aware resource allocation for D2D communication, using a sequential second price auction algorithm. In [5] the system throughput is enhanced by choosing user's communication mode in a reasonable manner to reduce the interference caused by D2D users in the cellular network when reusing the cellular resources. In [6] the authors propose a method based on D2D user's QoS requirements, which allocates the resource flexibly and efficiently rather than reusing a fixed cellular user's resource. In [7] a power control scheme is proposed to reduce the interference of D2D link to the cellular link when the SINR of the cellular link is declining. Reference [8] deduces the optimal power allocation in the scenario of a cellular user and a pair of D2D users, and increases the total throughput of the system by ensuring the priority of the cellular user. In [9] the authors propose a resource allocation algorithm based on Signal to Noise Ratio (SNR) equalization, which establishes convex optimization to maximize the total system throughput by optimizing the received interference power and balancing SNR of all users. In [10] a sharing resource allocation algorithm is suggested based on the dynamic power control, which adaptively adjusts the transmission power of D2D equipment in each Resource Block (RB) to minimize the interference to the cellular network. In [11] the authors offer a dynamic power control scheme based on the channel conditions of the cellular and D2D users, which adjusts the transmission power of D2D user with a predefined D2D coverage threshold to efficiently reduce the interference of D2D to the cellular system.

This paper proposes a joint resource allocation scheme based on user's QoS requirements and a power control algorithm based on convex optimization for D2D communication under a downlink cellular network to improve the spectrum efficiency. In this work the interference that D2D users bring to the cellular users is under the threshold which the cellular users can bear. Meanwhile, the QoS requirements of D2D and cellular users are guaranteed respectively. This paper is organized as follows: the background and the related work of D2D communication technology is introduced in Section 1; the system model and the proposed joint resource allocation scheme are described in details in Section 2; simulation results are shown in Section 3. Finally, concluding remarks are given in Section 4.

2. System model and the proposed scheme

2.1. System model

This paper focuses on the scenario of multiple User Equipments (UEs) and an Evolved Node B (eNodeB) located in the center of the single TD-LTE network, in which a cellular link and several D2D links are multiplexed on the same downlink Orthogonal Frequency Division Multiplexing (OFDM) RB. The two types of UEs are Cellular User Equipment (CUE) and D2D User Equipment (DUE). DUEs exist in pairs with a D2D transmitter and a D2D receiver. The system architecture is illustrated in Fig. 1. There are M CUEs with a set of $\mathbf{M}_{\text{CUE}} = \{\text{CUE}_m | m = 1, 2,\ldots, M\}$ and N D2D pairs with a set of $\mathbf{N}_{\text{D2D}} = \{\text{D2D}_n \mid n = 1, 2, \ldots, N\}$, in which the n-th D2D transmitter can be presented as D_n^{T} and the n-th D2D receiver can be presented as D_n^{R}.

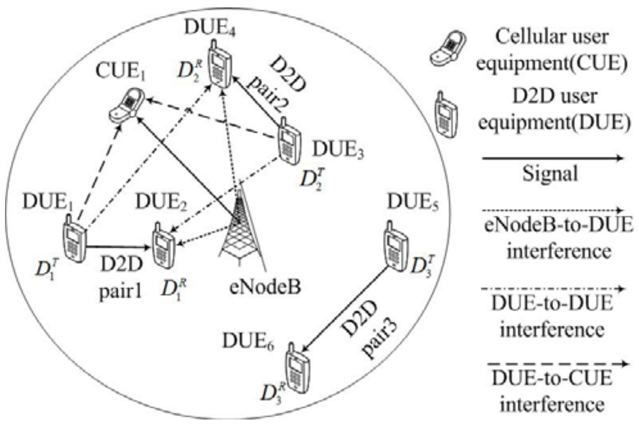

Fig. 1. System model

In order to simplify the model, some assumptions are accepted:

1. The system bandwidth is divided into equal RB, and the number of RBs is equal to the number of CUEs.

2. Each CUE takes up only one RB, and CUE_m is expressed as the m-th CUE occupying the m-th RB.

3. All the RBs are assigned to each CUE in the system to ensure the CUE communication requirements preferentially due to D2D communication under the cellular network.

4. DUEs are scheduled to reuse the resources according to the D2D communication requirements in each Transmission Time Interval (TTI) in the system scheduler.

The communication situation shown in Fig. 1 shows a simple model. There is one CUE_1 and three D2D pairs with two pairs (D2D pair1, D2D pair2) reusing the CUE_1's RB. CUE_1 receives a signal from eNodeB and interference from D2D transmitters DUE_1 and DUE_3, as well as in the downlink communication. D2D receiver DUE_2 receives not only the signal from D2D transmitters DUE_1 in D2D pair1, but also the interference from the eNodeB and another D2D transmitter DUE_3 in D2D pair2. The signal and interference received by D2D receiver DUE_4 is similar to DUE_2.

2.2. The proposed scheme

The aim of the proposed scheme is to satisfy the user's communication requirements when D2D users reuse the sharing resource and control the interference that D2D users brought to the CUEs in order to improve the performance of the whole system. In the scheme, the CUEs are primary users with absolute priority of the resources in the cellular system, and D2D users are secondary users under the cellular network.

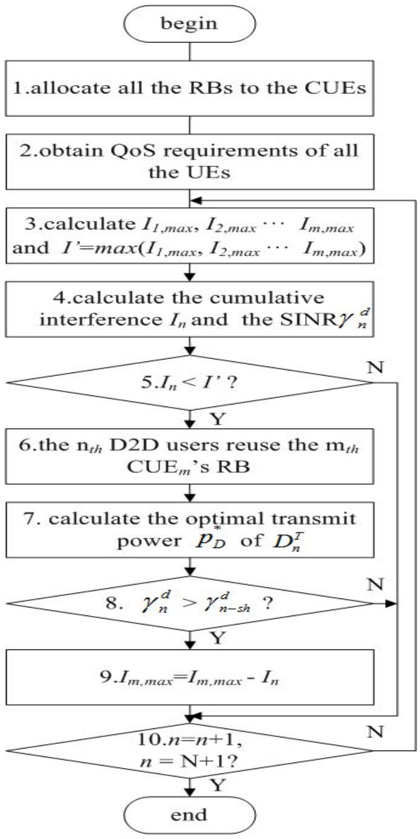

Fig. 2. Flowchart of the joint resource allocation scheme

The flowchart of the joint resource allocation scheme is shown in Fig. 2, and the main steps are as follows:

Step 1. Allocate all RBs to the CUEs.

Step 2. The eNodeB obtains QoS requirements of all UEs of CUEs and DUEs by decoding the Sounding Reference Signal (SRS) respectively.

Step 3. Calculate the maximum interference threshold $I_{1,\max}$, $I_{2,\max}$, …, $I_{m,\max}$, each CUE can withstand according to its communication requirements, and obtain the maximum value $I' = \max(I_{1,\max}, I_{2,\max}, \ldots, I_{m,\max})$ in each downlink slot in each frame.

Step 4. Calculate the cumulative interference I_n the n-th D2D transmitter D_n^{T} brought about when reusing the m-th CUE$_m$'s RB, and calculate the SINR γ_n^d of n-th D2D receiver D_n^{R};

Step 5. If the cumulative interference I_n D_n^{T} brought about when reusing the m-th CUE$_m$'s RB is smaller than I', go to the next step, otherwise go to Step 10.

Step 6. The n-th D2D users reuse the m-th CUE$_m$'s RB.

Step 7. Calculate the optimal transmitting power p_D^* of D_n^{T} when it reuses the m-th CUE$_m$'s RB.

Step 8. If the SINR γ_n^d of n-th D2D receiver D_n^{R} is greater than the predefined SINR threshold $\gamma_{n-\mathrm{sh}}^d$ when reusing the m-th CUE$_m$'s RB, go to the next step, otherwise go to Step 10.

Step 9. $I_{m,\max} = I_{m,\max} - I_n$.

Step 10. If all DUEs are assigned resources, end the procedure in this TTI, otherwise return to Step 3 to continue for the rest of the DUEs.

In order to satisfy the communication requirements of the m-th CUE$_m$ when D2D users reuse the resource, the downlink SINR of CUE$_m$ must conform to

(1) $$\frac{p_{\mathrm{B}} g_{m,\mathrm{BC}}}{\sigma^2 + I_m} \geq \gamma_{m-\mathrm{sh}}^{\mathrm{c}}.$$

In the above equation, p_{B} is the transmission power of eNodeB, $g_{m,\mathrm{BC}}$ is the channel gain between eNodeB and the m-th CUE$_m$, σ^2 is the average power of noise, I_m is the interference that the m-th CUE$_m$ can withstand, and $\gamma_{m-\mathrm{sh}}^{\mathrm{c}}$ is the minimum SINR threshold of the m-th CUE$_m$.

Taking Formula (1), we have:

(2) $$I_{m,\max} = \frac{p_{\mathrm{B}} g_{m,\mathrm{BC}}}{\gamma_{m-\mathrm{sh}}^{c}} - \sigma^2.$$

The cumulative interference I_n which the n-th D2D transmitter brings about when reusing the m-th CUE$_m$'s RB must conform to

(3) $$I_n = \sum_{n \in \mathbf{D_N}} p_{\mathrm{D}}^n g_{n,\mathrm{CD}} \leq I_{m,\max}.$$

In (3), p_{D}^{n} is the transmission power of the n-th D2D transmitter, $g_{n,\mathrm{CD}}$ is the channel gain between n-th D2D transmitter and the m-th CUE_m, $\mathbf{D}_{\mathrm{N}}$ is the set of D2D pairs reusing the same resource of the cellular network.

In order to guarantee the communication requirement of the n-th D2D receiver when reusing the resource, the downlink SINR of D_n^{R} must conform to

(4) $$\frac{p_{\mathrm{D}}^{n} g_{n,\mathrm{DD}}}{p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sigma^2 + \sum_{k \in \mathbf{D_N},\, k \neq n} p_{\mathrm{D}}^{k} g_{k,\mathrm{DD}}} \geq \gamma_{n-\mathrm{sh}}^{d}.$$

Here (4) $g_{n,\mathrm{DD}}$ is the channel gain between the n-th D2D transmitter and D2D receiver, $g_{n,\mathrm{BD}}$ is the channel gain between eNodeB and the n-th D2D receiver, $\gamma_{n-\mathrm{sh}}^{d}$ is the minimum SINR threshold of the n-th D2D receiver, and $\sum_{k \in \mathbf{D_N},\, k \neq n} p_{\mathrm{D}}^{k} g_{k,\mathrm{DD}}$ is the cumulative interference that k D2D transmitters except for the n-th D2D transmitter have brought about when reusing the m-th CUE_m's RB.

The optimal transmission power of the n-th D2D transmitter must be adjusted according to the performance of the whole system when reusing the m-th CUE_m's RB. In order to determine the optimal transmission power p_{D}^{*}, a new utility function $U(p_{\mathrm{D}}^{n})$ is defined with the variable p_{D}^{n} as follows:

(5) $$\begin{cases} U(p_{\mathrm{D}}^{n}) = \dfrac{B}{N} \log_2 \left(1 + \dfrac{p_{\mathrm{D}}^{n} g_{n,\mathrm{DD}}}{p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sigma^2 + \sum_{k \in \mathbf{D_N},\, k \neq n} p_{D}^{k} g_{k,\mathrm{DD}}} \right) - \alpha p_{\mathrm{D}}^{n} g_{n,\mathrm{CD}} \\ \text{subject to } 0 < p_{\mathrm{D}}^{n} < p_{\mathrm{DUE}}^{\mathrm{MAX}}, \end{cases}$$

where B is the system bandwidth, $p_{\mathrm{DUE}}^{\mathrm{MAX}}$ is the maximum transmission power of the D2D transmitter, $\frac{B}{N} \log_2 \left(1 + \frac{p_{\mathrm{D}}^{n} g_{n,\mathrm{DD}}}{p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sigma^2 + \sum_{k \in \mathbf{D_N},\, k \neq n} p_{\mathrm{D}}^{k} g_{k,\mathrm{DD}}} \right)$ is the system revenue obtained by D2D communication, $p_{\mathrm{D}}^{n} g_{n,\mathrm{CD}}$ is the system cost due to the interference that D2D communication brings about, and α is the cost factor referred to the proportional influence to the system.

There is no coupling relationship between each pair of D2D, so that the transmission power of the D2D transmitter can be optimized respectively. The optimization problem is a Mixed Integer Non-Linear Program (MINLP) given by (5). Calculating the second derivative of (5), we have

(6) $$\frac{\partial U(p_D^n)}{\partial p_D^n} = \frac{B}{N \ln 2} \frac{g_{n,\mathrm{DD}}}{p_{\mathrm{D}}^{n} g_{n,\mathrm{DD}} + p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sigma^2 + \sum_{k \in \mathbf{D_N},\, k \neq n} p_{\mathrm{D}}^{k} g_{k,\mathrm{DD}}} - \alpha g_{n,\mathrm{CD}},$$

(7) $$\frac{\partial^2 U(p_{\mathrm{D}}^n)}{\partial (p_{\mathrm{D}}^n)^2} = -\frac{B}{N\ln 2}\frac{g_{n,\mathrm{DD}}^2}{\left(p_{\mathrm{D}}^n g_{n,\mathrm{DD}} + p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sigma^2 + \sum_{k\in \mathbf{D_N},\, k\neq n} p_{\mathrm{D}}^k g_{k,\mathrm{DD}}\right)^2} < 0.$$

$U(p_{\mathrm{D}}^n)$ is the concave function of p_{D}^n due to the fact that (7) is less than zero, and the constraint in (5) is a convex set; therefore (5) presents convex optimization. The the Lagrange function of the optimization problem be constructed based on the convex optimization theory [12] as follows:

(8) $$L(p_{\mathrm{D}}^n, \lambda) = U(p_{\mathrm{D}}^n) + \lambda(p_{\mathrm{D}}^n - p_{\mathrm{DUE}}^{\mathrm{MAX}}),$$

where λ is the Lagrange multiplier. The optimal transmission power of the D2D transmitter can be obtained according to the Karush-Kuhn-Tucker (KKT) condition based on convex optimization. So the optimal value of p_{D}^n is as follows, solving the equation $\frac{\partial L(p_{\mathrm{D}}^n, \lambda)}{\partial p_{\mathrm{D}}^n} = 0$:

(9) $$p_{\mathrm{D}}^* = \frac{B}{N\ln 2(\alpha g_{n,\mathrm{CD}} - \lambda)} - \frac{p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sigma^2 + \sum_{k\in \mathbf{D_N},\, k\neq n} p_{\mathrm{D}}^k g_{k,\mathrm{DD}}}{g_{n,\mathrm{DD}}}.$$

According to the range of the transmission power of the D2D transmitter, the range of α is as follows:

$$\frac{B g_{n,\mathrm{DD}}}{N\ln 2 g_{n,\mathrm{CD}}\left(\sigma^2 + p_{\mathrm{B}} g_{n,\mathrm{BD}} + g_{n,\mathrm{DD}} p_{\mathrm{DUE}}^{\mathrm{MAX}} + \sum_{k\in \mathbf{D_N}, k\neq n} p_{\mathrm{D}}^k g_{k,\mathrm{DD}}\right)} + \frac{\lambda}{g_{n,\mathrm{CD}}} \leq$$
$$\leq \alpha < \frac{B g_{n,\mathrm{DD}}}{N\ln 2 g_{n,\mathrm{CD}}\left(\sigma^2 + p_{\mathrm{B}} g_{n,\mathrm{BD}} + \sum_{k\in \mathbf{D_N}, k\neq n} p_{\mathrm{D}}^k g_{k,\mathrm{DD}}\right)} + \frac{\lambda}{g_{n,\mathrm{CD}}}.$$

3. Analysis by simulation

The simulation scenario is shown in Fig. 3. The node with three sectors is eNodeB, and the UEs are only distributed in one sector of the eNodeB, located in the center due to the single cell studied in the system. There are 20 CUEs with random distribution and 6 pairs of DUEs distributed in the cell, in which CUE is represented as a point and the D2D transmitter is represented as a point with an antenna.

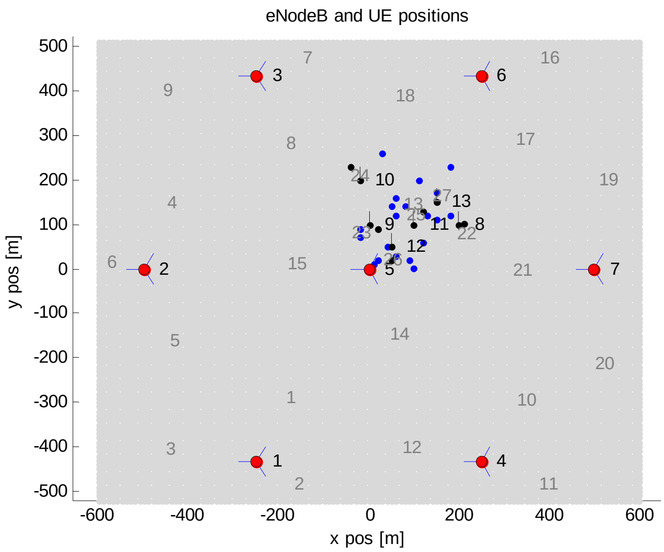

Fig. 3. Simulation scenario

The module of D2D is designed based on the Long Term Evolution (LTE) system level simulation platform developed by Vienna University of Technology [13], and the main parameters in the simulation are shown in Table 1.

Table 1. The main parameters in the simulation

Parameter	Value
Frequency	2.14 GHz
Bandwidth	1.4 MHz
Number of RB	20
Transmission power of CUE	23 dB.m
Maximum distance between a D2D pair	25 m
Maximum transmission power of DUE	23 dB.m
Transmission power of eNodeB	46 dB.m
Coverage of eNodeB	500 m
Number of CUE	20
Number of pairs of D2D	6
Density of noise	–174 (dB.m)/Hz
Simulation time	1000 TTI
Types of the traffic	full buffer
Scheduling algorithm of CUE	Proportion Fair (PF)
Channel model	suburban

In order to validate the performance, we compare the proposed scheme with the schemes of Random, Max-CQI and Interf-Min. The scheme of Random refers to assigning the resource to DUE randomly. Max-CQI refers to assigning the resource with a maximum Channel Quality Indicator (CQI) to DUE. Interf-Min refers to assigning the resource to DUE with the minimum interference to CUE. The transmission power of the D2D transmitter is adjusted by the utility function in the proposed one, while the others have full power.

Comparison of the Cumulative Distribution Function (CDF) with the average throughput of DUE is shown in Fig. 4. It is seen in the figure that the performance of the suggested scheme is the best one. The average throughput of DUE based on the Proposed sheme is stable from 0.2 Mb/s up to 0.25 Mb/s, while that of the other three schemes are relatively dispersed, and the overall throughput of the Proposed scheme is the greatest one.

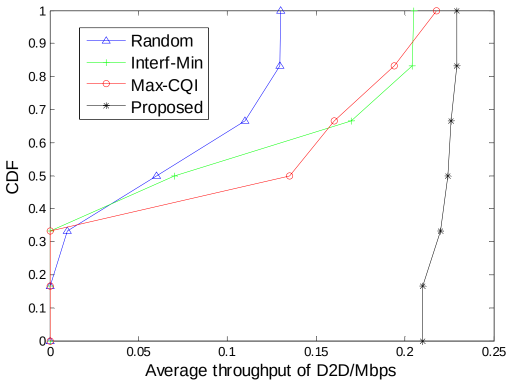

Fig. 4. Comparison of CDF with the average throughput of DUE

Comparison of the CDF with the average throughput of CUE is shown in Fig. 5 which shows that the difference between the maximum and minimum throughput of CUE is greater compared to Fig. 3. Since CUE is distributed randomly in the simulation scenario, a CUE close to eNodeB will obtain a greater throughput. Contrary to this, the throughput is smaller if the CUE is far away from eNodeB. In addition, the minimum and maximum throughput of the Proposed scheme are improved respectively for CUE compared to the other three schemes, and the overall throughput of the Proposed one is the greatest. This is due to the fact that the performance of CUE can be guaranteed when the resource is reused and the interference is controlled by adjusting the transmission power of DUE through the utility function.

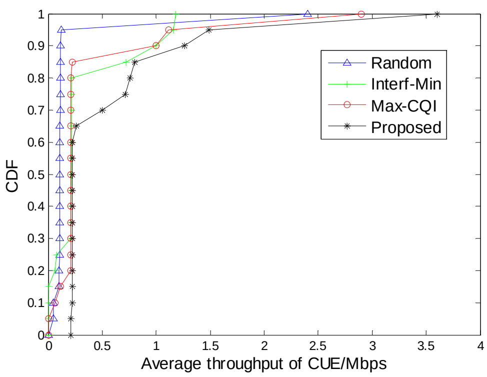

Fig. 5. Comparison of CDF with the average throughput of CUE

Comparison of CDF with the average throughput of all UEs is illustrated in Fig. 6, and the comparison of the average throughput with different types of UE is displayed in Fig. 7 by a histogram.

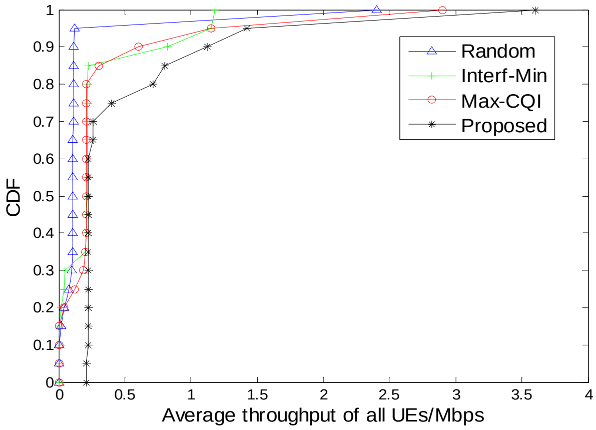

Fig. 6. Comparison of CDF with the average throughput of all UEs

The average throughput of the Proposed scheme is the best for CUE, DUE and all UEs respectively from Figs 6 and 7, because the resource is reused as much as possible to enhance the total throughput without affecting the communication requirement of CUE. Meanwhile, the transmission power of DUE is optimized by balancing the revenue (system throughput) and the cost (interference introduced by D2D). The average throughput of the Random scheme is the smallest one, because the resource is reused by DUE randomly without considering the channel condition and the interference is possibly produced by multiple DUEs reusing the same resource. The average throughput of Interf-Min is greater than Random, because the resource reused by DUE is the resource with minimum interference to CUE. The average throughput of Max-CQI is slightly greater than Interf-Min because the channel condition is reusing the resource of the maximum CQI.

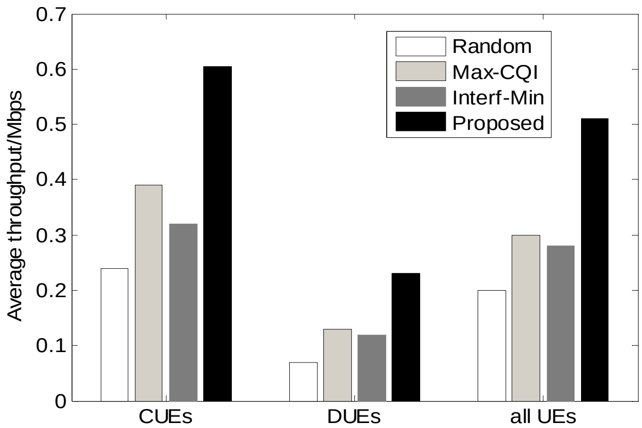

Fig. 7. Comparison of the average throughput with different types of UE

Involving D2D communication in the system leads to interference to the CUEs, and some communications of CUEs may be blocked because they cannot meet the minimum requirements. In order to compare the communication effect of CUEs with different algorithms, the CUE Satisfaction Degree (CSD) is defined as follows:

$$\text{CSD}=\frac{\text{Numbers of CUEs with communication successfully}}{\text{Total numbers of CUEs}}.$$

In Fig. 8 the powers of the DUEs can be adjusted with the Proposed scheme to reduce the interferences to the CUEs, so that CSD with the Proposed one is comparable with Interf-min. The influences of D2D communication to the CUEs are not considered with Random and Max-CQI, so that the CSDs are smaller than the Proposed one. Max-CQI reuses the maximum CQI without considering the interferences to the CUEs, so that CSD is the smallest one.

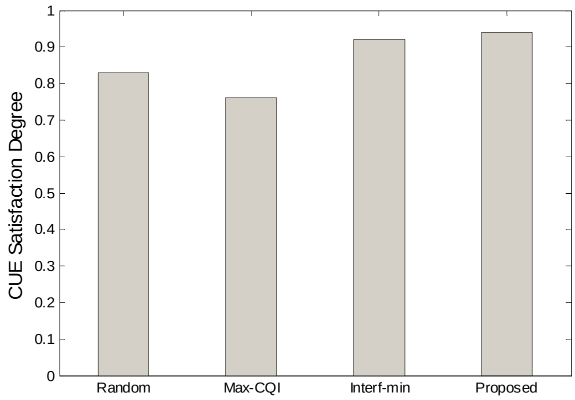

Fig. 8. Comparison of CUE Satisfaction Degree with different schemes

4. Conclusion

This paper proposes a joint resource allocation scheme based on the user's QoS requirement by analyzing the interference in D2D communication under a cellular network. The resource allocation is based on a greedy algorithm and the transmission power of D2D is optimized by the convex optimization theory to balance the enhanced throughput and the interference brought by D2D communication. The simulation shows that not only the user's QoS requirement can be guaranteed, but also the system throughput is improved with the users' balance. However, this work only considers a single cell model without considering the interference between multiple cells. For a further study, we are interested in studying the resource allocation scheme in multiple cells.

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